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STUDY OF THE PERFORMANCE CHARACTERISTICS OF AN EXPLOSIVE QUICK-STOP DEVICE FOR FREEZING CUTTING ACTION

P. K. PHILIP*

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Abstract—The design and operation of an explosive quick-stop device conceived on the lines of an original design by Hastings is described. Design considerations for its elements are indicated. Its performance during cutting and freezing of cutting action is assessed and the criteria for determining its efficiency discussed. The influence of the main operating parameters on its performance is presented and discussed.

1. INTRODUCTION

METAL cutting research, whether of a theoretical or applied nature, is mainly concerned with the phenomena at the cutting edge, the regions of prime interest being the shear zone the chip-tool contact zone and the flank region of the tool. Often several metallographic observations of these regions are necessary to investigate important phenomena such as crater and flank wear of the cutting tool or the plastic deformation associated with chip separation. This calls for obtaining a chip root under conditions truly representative of actual cutting through a freezing of the cutting action. Various quick-stop devices have been designed and made use of in the past for this purpose. These can be classified in to the following groups.

a. Drop tool devices
b. Devices employing one or more shear pins
c. Devices involving a breakage of the cutting tool
d. Arrangements using specially designed work pieces.

Drop tool devices employ the cutting force coupled with a spring force to retract the tool from the work piece during cutting [1]. The cutting edge in this case moves at an angle to the direction of instantaneous cutting velocity, thus causing a change in effective tool geometry during retraction of the tool. Moreover, due to the limited cutting and spring forces, the obtainable acceleration of tool motion is limited and distances that are significant compared to the ruling dimensions of the zones of interest are involved during tool retraction when the cutting action is stopped at the high cutting speed ranges.

Many of the existing devices employ one or more shear pins to take up the cutting force or the cutting torque and in some cases to control the acceleration of the tool at the start of its motion in the direction of relative cutting velocity. The energy source to shear the pin is one of the following.

a. A mechanically applied impact load.
b. Elastic deflection of a rigid obstruction introduced in to the path of the rotating work piece system [2].

* Indian Institute of Technology, Madras, India.

c. The explosive pressure of gases released through the ignition of a propellent [3].
d. The kinetic energy of a moving mass propelled by an explosion [4] & [5].

Devices involving a breakage of the tool employ either a mechanically applied shock load [6] or the impact of a fast moving mass actuated by an explosion [7] to break the tool and accelerate it out of the cut.

In a recent method, a specially designed work piece is machined using conventional tools to obtain a frozen chip [8]. In another case a work piece release system built in to the cutting stroke of the ram stops the cut in a shaping operation [9].

In evaluating the merits of the existing devices with a view to arrive at an optimum design, one has to bear in mind their main functions and requirements. The following are some of the more important of them.

a. A quick stop device should effect a separation of tool from work in such a short time that the unstable cutting action during separation should remain insignificant. In other words the cutting velocity should be brought down to zero in the minimum possible time so that the relative movement between tool and work remains small enough as not to influence the various phenomena involved in chip separation.
b. It should in no way interfere with normal cutting action and should possess good static and dynamic rigidity over the normal range of cutting conditions.
c. Versatility as adjudged in terms of adaptability to conventional machines without necessitating an additional fixture or of its capability to accommodate commercially available tools without requiring a modification in their shape.
d. Facility to vary and control its performance characteristics by changing the operating parameters.
e. A minimum of resetting time in between applications coupled with overall safety and inexpensiveness of operation.

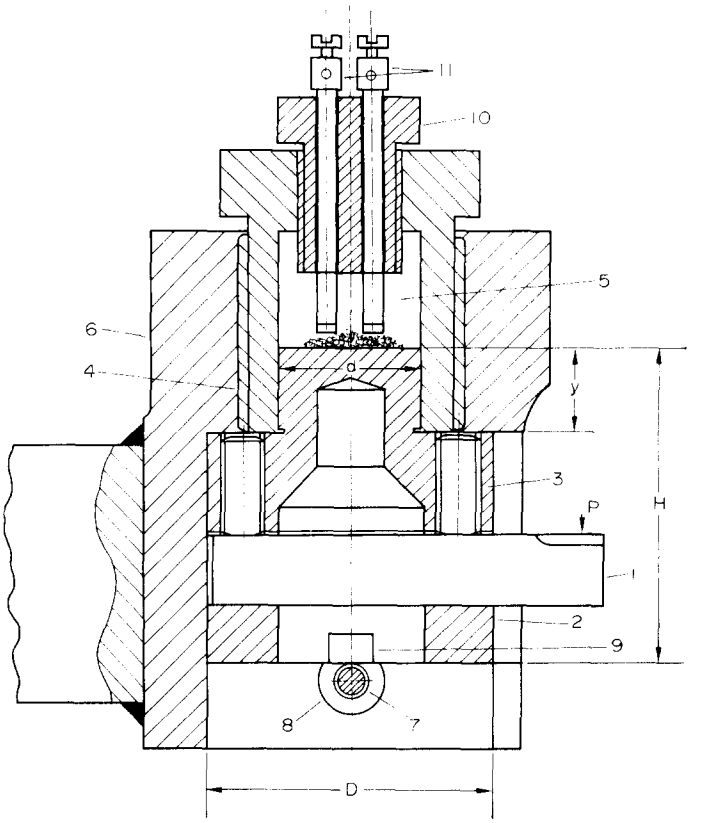
The performance in terms of time lapse for complete retraction of some of the devices have been compared [3] in the past, and also theoretical derivations ruling their retractive motions attempted [4], [6], [10].

2. A MODIFIED QUICK-STOP DEVICE

A quick-stop device for turning operation on the lines of Hastings [3] has been designed and built at the machine tool Laboratory of the Indian Institute of Technology, Madras. Fig. 1(a) and (b). The design is characterized by the following features.

a. A small number of component parts.
b. Reduced mass and a one-piece construction of the projectile holding the tool.
c. A simple and effective arrangment for preloading the shear pin and thus improving the rigidity and stopping efficiency of the device.
d. A variable combustion chamber volume.
e. A simplified electrical ignition system.

The tool is held in a hollow cylindrical unit [2] with the help of allen screws [3]. The upper portion of this unit serves as a piston inside a bush [4] screwed in to the holder [6]. The combustion chamber is indicated by [5]. The shear pin [7] resting in bushes [8] take up the cutting force and helps intial build up of gas pressure in the combustion chamber. The inserts [9] in conjunction with sharp-edged bushes create a stress concentration in the planes



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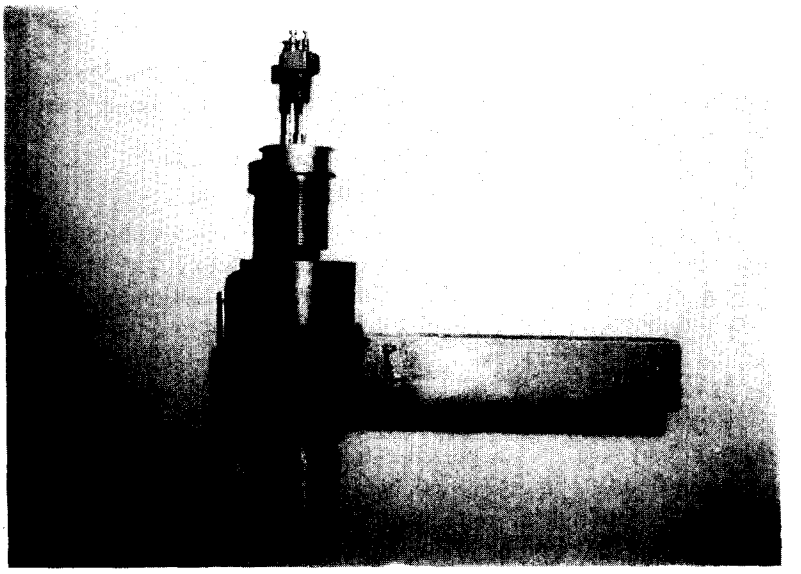


(*b*)

FIG. 1(a). A cross sectional view of the quick-stop device. (b). Quick-stop device assembly.

of shear when using normal pins*. The ignition assembly [10] holds the two terminals [11] and serves to vary the combustion chamber volume. A thin copper wire is strung across the terminals to ignite the charge.

Turning tools with a shank diameter of 12·5 × 12·5 mm can be used on the device, in orthogonal as well as oblique cutting. During operation the device is clamped in the tool holder of the lathe like a conventional turning tool. To reduce friction during motion a lubricant is smeared over the sliding surfaces before each test.

The effective static and dynamic rigidity of the tool at the cutting edge is decisively influenced by the overhang of the tool from the tool assembly. This is more so in the case of carbide tools as the shank cross section concerned is small. A small section is chosen to ensure a lesser imbalance in the mass distribution of the tool assembly. The tool overhang to the point of application of the mean cutting force is 18 mm for carbide tools. Also the free part of the tool slides through a guiding slot in the front part of the holder and prevents rotation of the tool assembly on release.

The screwed-in bush [4], which can be machined out of hexagonal stock, forms the combustion chamber as well as holds the tool assembly tightly pressed against the shear pin. By tightening it with a spanner a preload can be applied on the shear pin, so as to facilitate its fracture without significant initial shear deformation. Pieces of 6 mm dia. cold drawn brass rods were used as shear pins. Two sharp square-edged notches provide stress concentration at the planes of shear, and coupled with a preload on the pin, cause a sudden brittle fracture ofthe shear pin.

The ignition assembly [10] forms and governs the combustion space as well as holds the two terminals constituting part of the ignition system. The propellent used was gun powder up to a corn size of 0·1 mm. Copper wires 0·1 mm. in dia. serve as the igniting medium through a sudden explosive burning when a voltage of 24 V is applied across the terminals. The supply unit is a 24 V 15 A single phase transformer operating on 220 V net. The igniting wire is strung across the terminals forming a semi loop so that part of it is submerged in the propellent. The ignition is effected by throwing a switch. Each of the terminals has a step at the bottom to prevent it from being blown off and each one is insulated from the body through an encasing in Araldite. No single failure of the ignition system occurred in more than 200 tries. Stopping the tool assembly was done with plasticine in an adjustable container mounted on the saddle of the lathe.

3. DESIGN CONSIDERATIONS

The ruling dimension could well be the diameter of the combustion chamber. The effective thrust on the projectile varies with the square of this quantity. But the rigidity of the tool at the cutting edge decreases inversely with the tool overhang as well as the distance between the two securing screws. The smaller these dimensions, the more rigid the tool and the wider the range of stable cutting conditions. So a compromise has to be struck between these two contradicting demands in arriving at the chamber diameter. The height "y" should be large enough so that there is sufficient sealing for initial pressure build-up in the chamber and there is no drastic pressure drop till the retraction of the tool is complete. This sealing is of particular significance as cumulative errors and facility for easy insertion limit the quality of fit between the piston and the cylinder. The remaining portion of the total length "H" is governed by rigid clamping of the tool and a balanced distribution of

* As revealed through subsequent tests, pins notched at the planes of shear gave better performance and details (8) and (9) could be dispensed with.

bearing and sliding surfaces. As the time taken for complete retraction of tool is a function of tool acceleration, the mass of the tool assembly should be kept as low as possible avoiding a drastic asymmetry of mass distribution. In such a case it flies off at an angle on leaving the holder and could be hazardous. In the specific case the tool assembly weighed 650 g.

The height of the combustion chamber is governed by the desired chamber volume The size of the chamber in turn will depend on the type and quality of propellent used as well as the quantity of charge. An arrangement to vary the chamber volume is a desirable feature. The threaded connections between the bush and the holder and between the bush and the ignition assembly should be strong enough to withstand the instantaneous maximum pressure. The governing dimensions are not limited by the functional parameters of the device and a high factor of safety could be employed. Calculations leading to this should be based on the mass of the tool assembly and the desired acceleration rather than on shear pin strength.

4. PERFORMANCE

Micrographs of chip roots obtained at different cutting speeds are shown in Fig. 2(a), (b) and (c). These correspond to carbide cutting of a carbon steel C10 with a positive rake of 6° and a clearance angle of 5°.

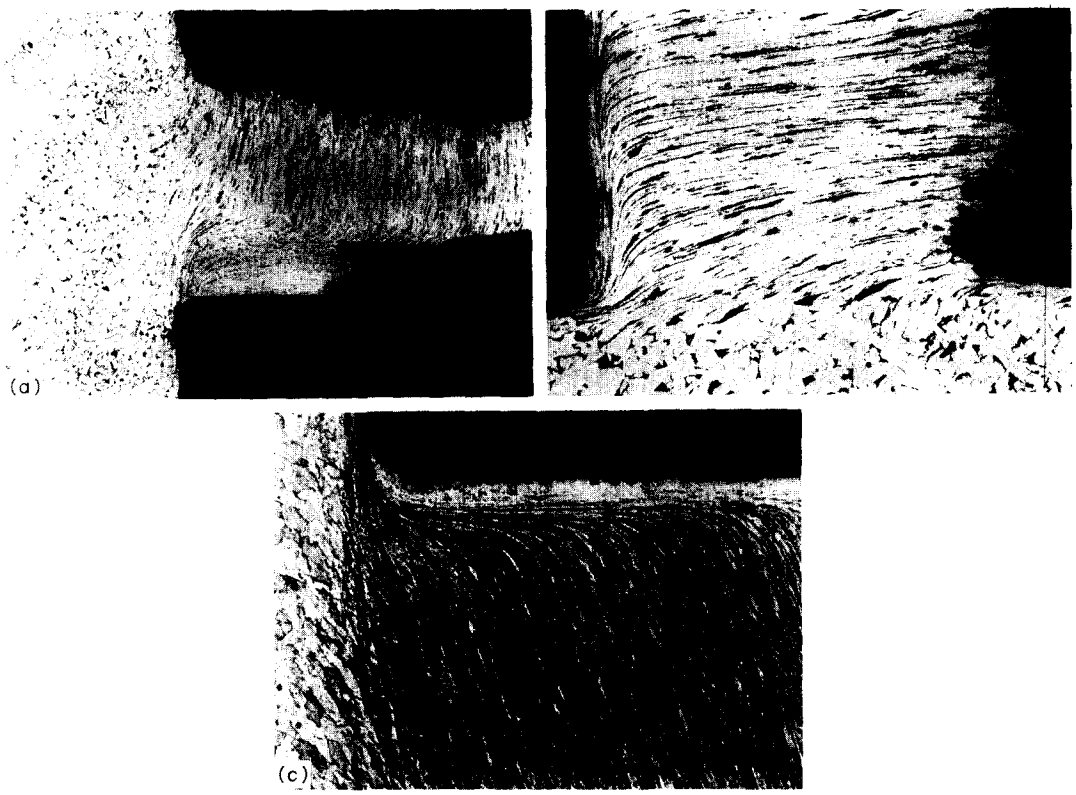


FIG. 2. Micrographs of chip roots obtained at different cutting speeds. Work—C10: Tool—carbide P30. $b = 3{\cdot}0$ mm, $s = 0{\cdot}15$ mm/rev, rake $\alpha = 6°$, clearance $\gamma = 5°$.

(a) $V = 40$ m/min. × 50. (b) $V = 60$ m/min. × 100. (c) $V = 120$ m/min. × 200.

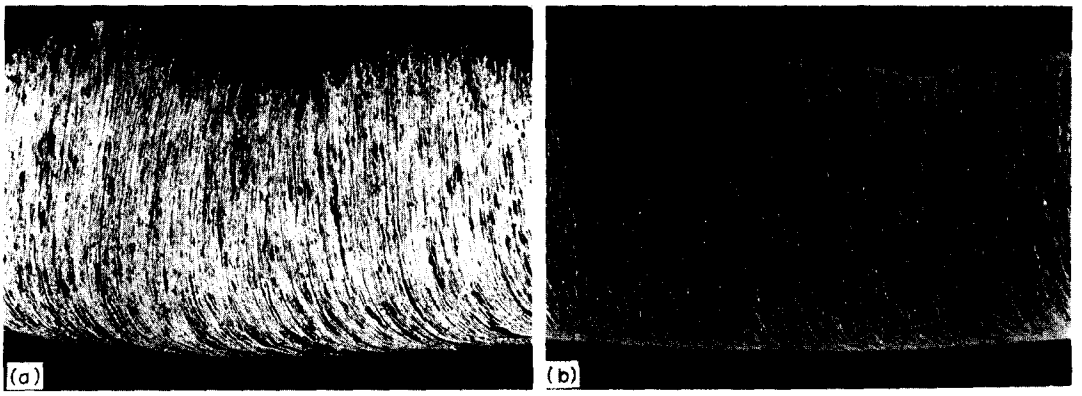


FIG. 3. Chip sections (a) at $V = 60$ m/min. (b) at $V = 120$ m/min.

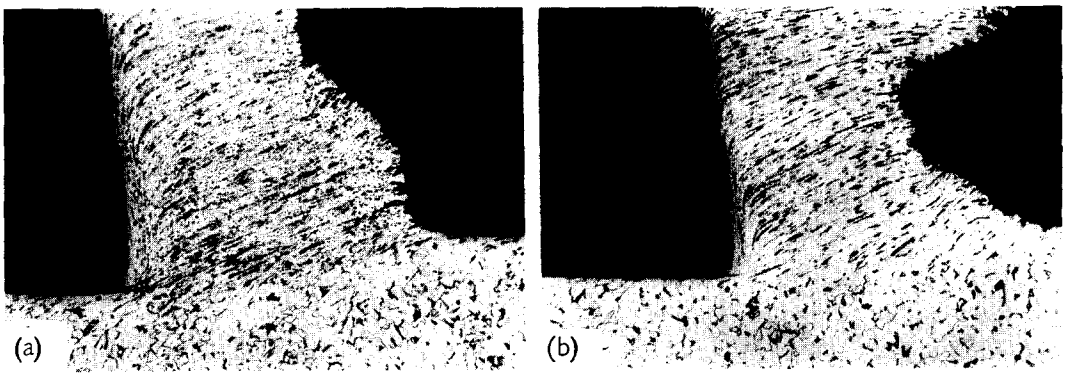


FIG. 4. Chip roots at (a) $V = 40$ m/min. (b) $V = 60$ m/min. $\times$ 50.

The uniformity of chip thickness has been considered by Kececioglu [1] and cited by Hastings [3] as a measure of the efficiency of a quick-stop device. But this can be due to operating parameters as seen in Fig. 3(a) and (b), where the only variable was cutting speed. Even a marked non-uniformity of chip thickness as seen in Fig. 4(a) and (b) could be due to reasons independent of the device. In the specific case this was due to surface undulations owing to work piece instability, as happens in the case when long thin-walled tubes are turned. This can be avoided by shorter tube lengths or cutting instantaneous tubes. A quick calculation will reveal that the non-uniformity of chip thickness at the chip root in the micrographs mentioned is unconnected with tool retraction.

5. INFLUENCE OF OPERATING PARAMETERS ON PERFORMANCE

The natural frequency of the device for the normal setting used for cutting with an excitation at the cutting edge in the direction of main cutting force was measured to be 850 Hz the second harmonic being 1300 Hz. The natural frequency showed a marked increase from 640 Hz to 850 Hz on increasing the preload on the pin from 1·0 kpm to 7·75 kpm.

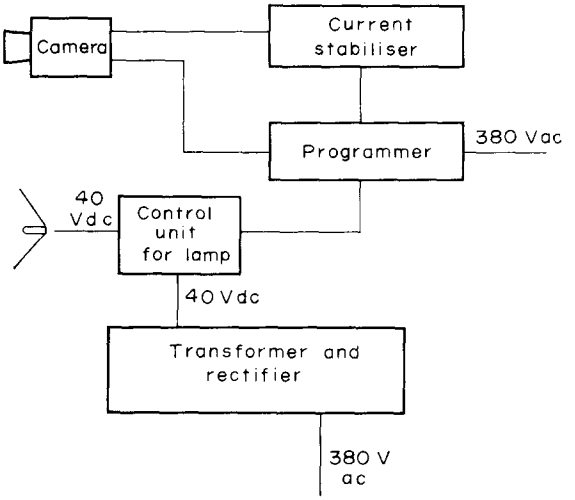


FIG. 5. Block diagram of high speed filming set up.

Time-displacement behaviour of the tool assembly in the early phase of its movement was ascertained with a high speed movie camera operating at 3000 frames per second for case (1) with an ordinary shear pin of 6 mm dia. without preloading and (2) with a shear pin having narrow sharp-edged notches and an effective diameter of 5 mm when preloaded with a torque of 7·75 kpm. A block diagram of the arrangement is shown in Fig. 5. It is seen that

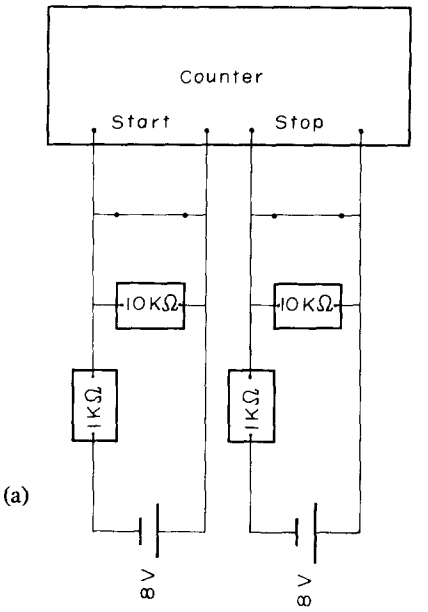
TABLE 1

Time $\frac{1}{3000}$ (sec)	Distance of tool travel (mm)	Acceleration (m/sec²)	Time for tool retraction at 100 m/min (msec)	Length of cutting during stopping (mm)
0	0			
		$0{\cdot}74\times10^{3}$	2·25	1·75
7	2·0			
		$0{\cdot}22\times10^{5}$	—	—
8	5·0			
		$0{\cdot}90\times10^{4}$	—	—
9	9·0			
		$1{\cdot}80\times10^{4}$	—	—
10	15·0			

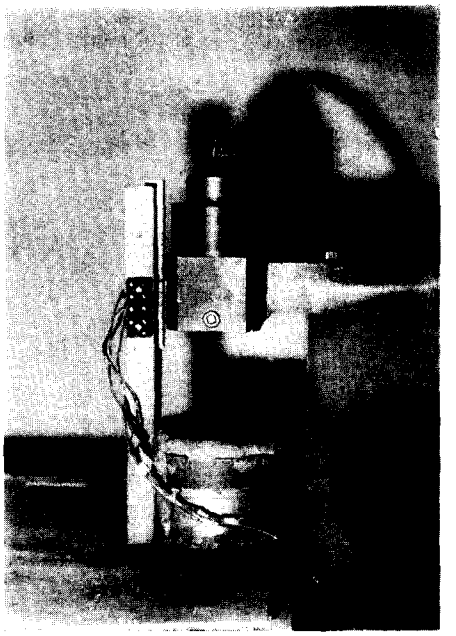
TABLE 2

Time $\frac{1}{3000}$ (sec)	Distance of tool travel (mm)	Acceleration (m/sec²)	Time for tool retraction at 100 m/min (msec)	Length of cutting during stopping (mm)
0	0			
		$0{\cdot}9\times10^{5}$	0·0185	0·0154
1	5·0			
		$1{\cdot}8\times10^{4}$	—	—
2	12·0			

in the first case considerable plastic deformation of the pin occurs at a rather low velocity before fracture sets in. The tool acceleration during this phase is low and a significant length of cut takes place under unstable conditions before the tool is completely free of the work.



(a)



(b)

FIG. 6. Arrangement for elapsed time measurement using an electronic counter: (a) block diagram, (b) actual set up.

The comparative values of acceleration and retraction time for both cases are presented in Table 1 and 2. It is inferred from the tables that the prime performance characteristic of the device is dependant on the mode of failure of the shear pin. A pin which fails in brittle fracture is to be employed to achieve a high initial acceleration of the tool.

The acceleration values presented in Table 2 do not represent the maximum that can be obtained using the device. So tests were made to evaluate the dependence of tool acceleration on the operating parameters of the device namely the strength of the pin, the quantity of propellent and the combustion chamber volume.

Figures 6(a) and (b) show a test arrangement for time-distance measure of tool motion after explosion. A tool with a modified tip travels through a narrow guide cutting two thin wires strung across its path. Breakage of the first wire starts an electronic counter and that of the second one stops it thus giving the elapsed time in between. The results are presented in Fig. 7 and Fig. 8.

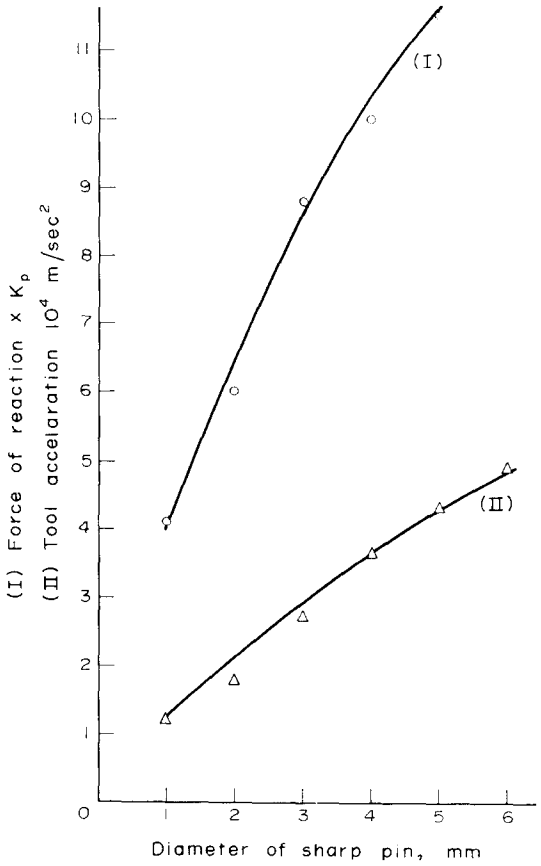


FIG. 7. Variation of reaction force and tool acceleration with shear pin diameter.

To check the trends obtained by the above test, qualitative assessment of the reaction force resulting from the ejection of the tool assembly was made using strain guages mounted on the free length of the holder and obtaining a record on a visicorder. The results are presented in Fig. 7 and Fig. 8.

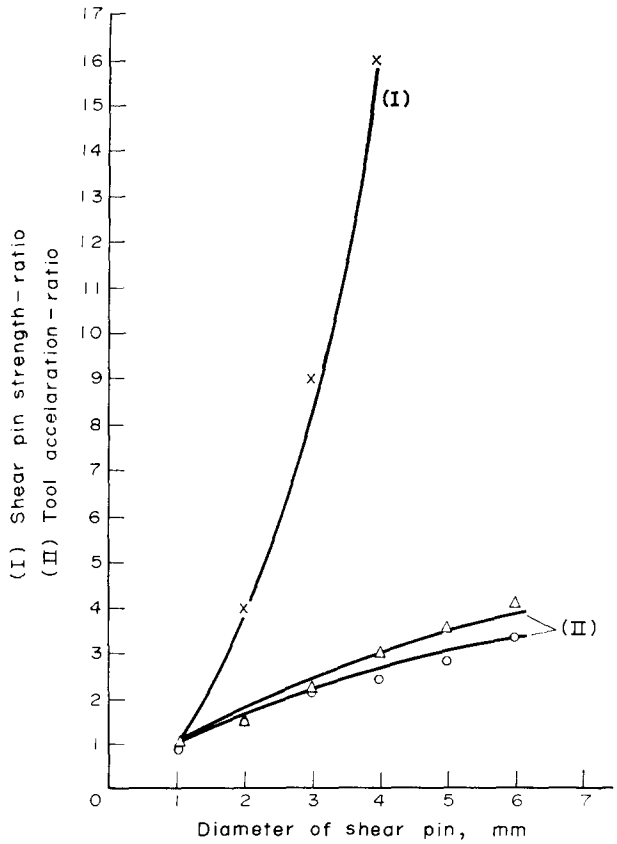


FIG. 8. Influence of shear strength of pin on tool acceleration.

Understandably there is an increase in acceleration of the tool assembly with increase in shear strength of the pin. But the relationship is far from being proportional, as would have been the case if the force of acceleration were to be derived from the shear strength of the pin. The force corresponding to an acceleration of 9×10^4 m/sec^2 of the tool assembly with a mass of 650 gms is 6000 Kp whereas the shear strength of a 5 mm dia. brass pin with a shear strength of 30 Kp/mm^2 is only 1180 Kp ignoring the notched geometry of the sections. It is to be concluded that the shear resistance of the pin significantly influences the pressure build up in the combustion chamber and thus the maximum instantaneous force available for accelerating the tool.

Figure 9 shows the effect of different quantities of propellent on tool acceleration. It is seen that this parameter has a more significant effect than shear pin resistance. The limiting factor is the overall strength of the device and safety considerations.

Indirect qualitative conclusions regarding the influence of combustion chamber volume could be drawn from the above test in which the same combustion chamber volume was maintained for a range of propellent quantity. With charges up to 2·0 g. the combustion was complete. But with larger charges efficiency was poor due to incomplete combustion.

The characteristic time-displacement behaviour of tool motion is depicted in Fig. 10.

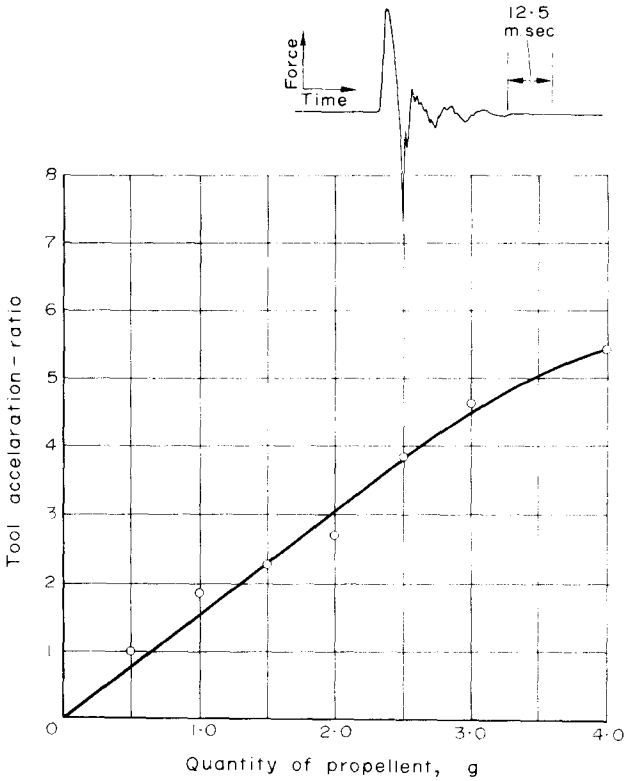


FIG. 9. Dependence of tool acceleration on propellant quantity.

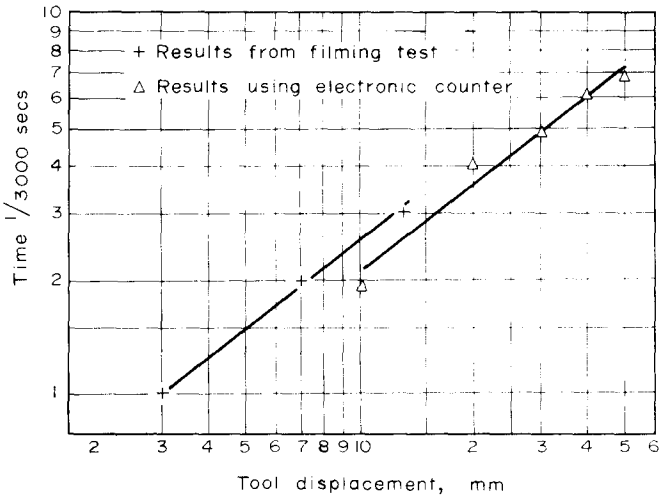


FIG. 10. Displacement–time behaviour of tool motion during retraction.

CONCLUSIONS

1. An explosive quick-stop is designed and being used for metal cutting research.
2. The design is characterized by a limited number of component parts, reduced mass of the projectile, an effective arrangement for preloading, a variable combustion chamber and a simplified ignition system.

3. The equipment is found to give stable performance in the lower and middle ranges of chip cross sections and the entire range of cutting speeds applicable to carbides.
4. The time of complete tool retraction as well as the dynamic stability during cutting are to be the criteria for evaluating the operating efficiency of the device.
5. The obtainable tool acceleration can be varied and controlled by changing the operating parameters of the device as presented.

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